RISK BASED PROFILING SYSTEM

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Dam Safety Risk Based Profile System
Instructions and Commentary
January 11, 2001

Introduction

In 1986, the Technical Priority Rating (TPR) System was developed to rank dams that are included in the Department of Interior's (DOI) inventory of dams. The TPR was included in an Interior Dam Safety Task Force "Report on Corrective Action Priorities", dated December 15, 1986. The goal of the TPR was to prioritize a large number of potential engineering and construction projects with one set of technical criteria. The TPR was based on known or assessed technical information which was obtained during the process of conducting dam safety activities (inspections, field investigations, analyses and corrective actions). While the TPR has served the Bureau of Reclamation (BOR) and the DOI well, it is not a risk-based system.

Purpose of Risk Based Profile System

An Independent Peer Review of the Dam Safety Program for the DOI was completed in January 1997. During the review, the Independent Peer Review Team identified concerns relative to the TPR used by DOI to identify and rank those dams with safety deficiencies and recommended the TPR be replaced with a risk-based system. Six practicing senior-level dam design engineers from the BOR, Technical Service Center, in Denver, Colorado, with a working knowledge of risk analysis, were given the task of developing a Risk Based Profile System (RBPS) to comply with the Peer Review recommendations and to meet the obligation of providing a risk-based rating tool to other DOI agencies. The RBPS has been developed, revised, and implemented by the BOR to improve its capability to prioritize dam safety activities and resources, and to identify those structures that represented the greatest risk to the public. The RBPS has also been offered as a prioritization tool to the other DOI agencies in addition to the BOR.

General Approach

For the RBPS to be fundamentally risk-based, it must incorporate the following concept:

Risk = (Probability of Load)(Probability of Adverse Response)(Consequences)

The RBPS can be used to characterize the risk associated with individual loading conditions such as hydrologic/hydraulic, seismic, or static (normal) loads, or can be used to sum the total risk imposed by a given structure. The probability of failure of a structure, or the risk of loss of life for structures, can be portrayed.

The "Failure Index" (Load x Response) for the hydrologic-hydraulic, seismic, and static cases are the foundation for the RBPS. These three cases are viewed as being the primary categories of how dams can fail. Significant operations, maintenance, and safety issues that are viewed as possibly resulting in life loss are also included. The RBPS assesses a dam by assigning a maximum of 1000 points to any structure. The higher the point total the greater the potential for failure for a given dam. By using readily available data and information, and engineering and scientific judgement, estimates of points distributions are made for a dam wotjom these four categories. hydrologic, seismic, static, and operations, maintenance, and safety cases can be compared on a common level.

An additional step to further prioritize and compare dams on a common risk-based level is to multiply the Failure Index by a Loss of Life Factor which characterizes the consequences associated with a failure as is done when determining the annualized loss of life in a risk analysis. This product is called the "Risk Index." This Risk Index is calculated separately for each category of Failure Index and then summed to represent the Total Risk Index.

It is emphasized that the RBPS is primarily intended to be used to examine how dams might be grouped relative to the risk that they pose due to potential for failure and/or loss-of-life, i.e., it prioritizes dams in a broad sense. In other words, is Reclamation (or other DOI agencies) focused on dealing with the highest risk structures in its inventory? While the risk based profile system could be used to differentiate between two individuals dams, and the need for proceeding with dam safety actions associated with one dam or the other, this is not the sole purpose of the RBPS. Minor differences in Index totals (points) should not be used as the basis for making decisions related to dam safety and dam safety program management.

There are a number of "operating" principles that might be imposed by program managers when using the RBPS. These principles could be similar to some of those presently employed by BOR (and other DOI agencies) when using the TPR.

- Consequences of potential for loss of life and social/economic impacts are considered in the RBPS. A measure of potential social and economic impacts are reflected through use of the Socio-Economic Index. For the purposes of the RBPS, the term "social" is assumed to grossly include cultural and environmental consequences. Specific and more refined factors that may enter significantly into the decision-making process related to social, economic, cultural and environmental consequences could be incorporated into the RBPS in the future by dam safety program managers.

- Ratings should not change from the time construction of modifications begins until structural performance of the newly modified dam has been proven by operations. The status of a dam should not change from "construction" to "complete" until the dam and its appurtenant structures have performed satisfactorily.

- RBPS ratings could be "frozen" in instances where BOR has taken an interim action(s) to reduce short-term risk. This would permit priority to still be given to projects where long-term risk reduction measures may be required.

<u>Level of Effort Required and Data Needed</u>

The level of effort required to complete an evaluation of a dam using the RBPS has been shown to take about one day or less by an experienced engineer. . Data needs are information that is readily available or identified during an examination of the dam. These data and information would include any past examination reports, Reports of Findings, Performance Parameters, population at risk estimates, identification of the 100-year flood event and related hydrologic data, seismic loads available on the Internet (peak horizontal acceleration that has a 2 percent chance of occurring in 50 years) from the National Seismic Hazard Mapping Project, access to summaries of previous analyses, the Emergency Action Plan, and decision-making information. The use of sound engineering judgement is also an obvious, but important factor, in completing a rating of a dam using the RBPS.

The RBPS is to be updated as necessary and peer reviewed as part of the Comprehensive Facility Review.

Information on the background, and details on use, of the individual portions of the system can be found in the following descriptions for each of the Appendices.

<u>Worksheet A - Static Response Factor for Embankment Dams</u>

Worksheet A of the Risk Based Profile System rates an embankment dam into four approximately equally weighted categories.

<u>Outlet Works</u>

This category recognizes the main component of an embankment dam that is generally recognized as being the single contributor to many historical dam safety incidents. Also it is the one component that is unarguably prone to direct deterioration with age. The 'poor details' listed are those that can be related to embankment internal erosion failure modes. They are also those that can typically be determined from design drawings (or reasonably extrapolated from known conditions) or determined from detailed inspections. In most instances, inspections from within the outlet works (as provided by direct access or by modern video inspection techniques) will be needed.

Dams without an outlet works or with an outlet works located in a tunnel isolated from the embankment do not receive an outlet works score.

Dams with a conduit penetration through the embankment that is provided as a spillway should also be ranked in this category (use the higher of the two rankings if the dam has both an outlet works and spillway).

The location of the control valve in the outlet works is viewed as an important component of the ranking. Structures works with a control at the downstream end receive a multiplier of 4 in recognition of the lack of inspection or inability to shut off the structure should a rupture in the conduit form. Structures with a control located in the middle of the dam with the conduit located within an access tunnel receive a multiplier of 1 (type factor) in recognition of the ease of inspection and isolation of the flows from the embankment (should a rupture form) that is provided by this type of design.

Scoring:

- Each of the six rating factors receive 4 pts. (up to a maximum of 19 pts - it only takes 5 of the six to get the maximum pts.)

- These points are then multiplied by a type factor of between 1 to 4 depending on the location of the control valve in the outlet works.

Reservoir Filling History

This category provides for ranking of a dam based upon the maximum historic reservoir level reached to date. Dams that have not experienced a reservoir load for a significant portion of their height are known to be in a higher risk category than those that have been sucessfully operated to near full conditions. The factors are based on hydraulic height since storage can be prolonged at these elevations. Storage above the maximum controllable water surface would be of short duration.

The hydraulic height used in the "Reservoir Filling History" section in worksheet A (static response factor for Embankment Dams) and worksheet B (static response factor for Concrete Dams) of the RBP's is defined as:

For Dams/Dikes on a Stream/River - The difference in elevation between the maximum controllable water surface (1. top of joint use, if applicable; 2. top of active conservation, if there is no top of joint use and is applicable; 3. normal water surface, if neither top of joint use or top of active is not defined) and the streambed elevation at the dam axis.

OR

For Dam/s Dikes not on a Stream/River - Similar definition for maximum controllable water surface, but rather than streambed elevation at dam axis, use lowest original ground elevation at dam axis (may have to estimate/approximate).

OR

For "Freeboard" Dikes - When the maximum controllable water surface is at or below the lowest original ground elevation of a dike (hydraulic height <= 0), enter "0" points in worksheet A or B, by selecting "Reservoir filled 95% to 100% or more of hydraulic height".

Be sure to document the determination of hydraulic height in the comment field for this worksheet.

Scoring:

Filling History	Scoring
Reservoir never filled to 50% of hydraulic height	75 pts.
Reservoir filled 50% to 75% of hydraulic height	50 pts.
Reservoir filled 75% to 90% of hydraulic height	25 pts.
Reservoir filled 90% to 95% of hydraulic height	10 pts.
Reservoir >= 100% of hydraulic height	0 pts

Seepage and Deformation

This category provides for ranking based on observations at the dam recognized to be precursors of potential problems. 'Critical' observations are those that are generally recognized as being alarming. 'Significant' items are those that may be indicative of a potential problem but not of a directly alarming nature.

Scoring:

- Either of the critical factors = 79 pts.
- # of Significant factors / Pts.

# of Significant factors	Pts.
1	5
2	10
3	20
4	30
5 or more	40

Embankment Design, Geology, and Embankment Monitoring

These three subcategories are provided to recognize the contributions that design, geology and monitoring add to the assessment of risk.

The items included under embankment design and construction are those that are recognized as contributing directly to the likelihood of a internal erosion incident.

The items included under geology are those that are known to be contributors to internal erosion and/or slope instability.

The items under embankment monitoring recognize the role that instrumentation and monitoring play in the potential for detecting problems with a dam.

Worksheet B - Static Response Factor for Concrete Dams

Worksheet B of the Dam Safety Risk-Based Profile System is used in a similar manner to that for Worksheet A and provides a simple way of summarizing the performance of concrete dams when subjected to normal, static loading conditions. The five main categories for determining this performance are very similar to those used for embankment dams, and include: Reservoir Filling History, Foundation/Geology, Existing Condition of Concrete Dam, Dam Design and Construction, and Monitoring. A maximum of 300 points are allocated among the five categories. The items listed in each category are reviewed, checked if present at the dam being evaluated, and points are assigned and summed to determine the total Static Response Factor for the dam.

The main concerns with the static performance of concrete dams reflected in this Worksheet include:

- First filling of the reservoir or reservoir levels exceeding previous historic maximums. Case studies of failures of concrete dams show the potential for failure of a concrete dam is much greater during first filling than during any other period of the life of the dam. Please refer to the discussion on determining the hydraulic height included for Worksheet A.

- Potential foundation failure due to adverse orientations of jointing, faulting, or bedding planes. The most likely failure mode for a concrete dam, based on historical performance data, is failure of the foundation.

- The poor condition of the existing dam such as unbonded lift lines, excessive seepage, non-functioning drainage systems, or cracked or spalled concrete. These conditions alone may not necessarily point to a dam safety deficiency, but they may be indicators that performance of the dam is deteriorating or less than desirable.

- The results of structural analyses performed for the dam for static loads and the absence of certain design features that are now considered prudent for the safe performance of concrete dams.

- The adequacy and frequency of visual and instrumented monitoring of the performance of the dam.

Worksheet C - Hydrologic Failure Index

Scoring for hydrologic loading conditions is based on five factors including: the discharge capacity of the spillway, surcharge storage capacity of the reservoir, the resistance of the dam to overtopping, size of the drainage basin, and the extent to which snowmelt is incorporated into the estimate of the 100-year flood. The principle concern in determining hydrologic risk is determining whether or not the flood can be routed through the waterways. Two key indicators of a dam's ability to safely route a flood are the spillway capacity and the volume of the reservoir above the active conservation pool. The combination of these two indicators can provide a reasonable assessment of a dam's ability to pass severe floods based on generally available information. More weight is given to the basic score for spillway capacity since a greater spillway capacity would provide greater safety from multiple hydrologic events in a short time span. If a dam has been modified or determined to be capable of sustaining overtopping, the top of the dam should be considered to be one of the dam's waterways.

Information regarding the PMF is input for the purpose of limiting scores for those dams which are capable of passing the PMF without failure. If the PMF can be passed without overtopping the dam, then the hydrologic score is considered to be 0.

Data to be used in scoring can be found in several sources. Specific information about waterway capacities and surcharge storage capacity can be found in the Waterways and Concrete Dams Group files. Information regarding 100-year flood studies are generally included with PMF (Probable Maximum Flood) studies located in the files of the Flood Hydrology Group. In many cases, 100-year flood hydrographs have been developed as antecedent conditions to the PMFs and are generally discussed in the latest PMF studies. If no 100-year flood peak and volume information is available, a crude estimate of the peak flow can be obtained by regression of USGS gauging station information. An estimate of the volume can be obtained using the rational formula (Q=ciA) in conjunction with 100-year rainfall estimates from "Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years." This reference is also known as TP-40 and is available from the National Weather Service. If multiple 100-year floods have been estimated, the most critical situation should be determined and entered into the system.

Spillway capacity is evaluated by comparing spillway discharge capacity with the reservoir water surface elevation at the top of the dam to the peak inflow of the 100-year flood. Dams which can pass greater multiples of this peak inflow provide a greater degree of protection. While the traditional PMF does not directly control the score, it places an upper limit on the number of multiples of the 100-year flood inflow that a spillway would need to pass to be considered safe even by deterministic standards. Considering several large drainage basins, it appears that this limit could be in the vicinity of 4 times the peak 100-year flood inflow. A basic score is determined from Table 1.

When smaller basin sizes are considered, it appears that the difference between the peak inflow of the 100-year flood and the PMF becomes greater. On smaller basins, it is also possible for smaller but more intense storms to generate floods in which there would be little if any warning to the downstream population at risk. To account for this increased risk, the basic score is multiplied by a factor from Table 2.

Dams which have large surcharge and/or flood control volumes can pass larger floods (given equal spillway capacity) due to a portion of the flood being stored in the reservoir. However, spillway capacity is preferred since the flood control or surcharge space doesn't have the capacity to accommodate a series of severe storms. For purposes of scoring, the flood control/surcharge capacity is defined as the capacity between top of active conservation and the lowest point in the crest of the dam. The basic score for flood storage is determined from Table 3 by comparing volume of space available to the volume of the 100-year flood.

Special note for dams with parapet walls:

> **DO** use the parapet wall in your calculation of surcharge storage for floods (worksheet C) if the wall is of adequate quality (structurally and hydraulically) to add flood storage to the reservoir.
>
> **Don't** use parapet walls for surcharge flood storage (worksheet C) if the wall is not of adequate quality for flood storage.

In mountainous basins, the volume of the 100-year flood can be dominated or significantly influenced by melting of the snow pack on the basin. If the source of the 100-year flood is a flood study in which the snowmelt has been addressed, there is no adjustment necessary. However, if the 100-year flood volume is estimated from rainfall, the storage score should be adjusted based on the expected influence of snowmelt on the basin. Adjustment factors are provided in Table 4.

Since some dams are more resistant to overtopping than others, an adjustment factor is provided in Table 5 to account for the increased risk at dams which are less capable of sustaining overtopping.

The total score for hydrologic response is computed as:

[(Basic Score A * F1) + (Basic Score B * F2)] * F3 = Hydrologic Failure Index

The maximum allowable score is 300 points.

Note: When a dam is modified to address hydrologic loads, the score would be expected to be lowered due to additional spillway capacity (or overtopping protection), additional surcharge storage, or both. Likewise, a string of severe hydrologic events could raise the score by leading to an increased estimate of the 100-year flood.

<u>Worksheet D - Seismic Load Factor</u>

The seismic load factor is based on the expected peak horizontal ground acceleration at the site that has a 2% chance of occurring in a 50 year period. This is equivalent to a return period of about 1/2500 years. This information is easily obtained from the USGS internet site described in the Worksheet and provides a reliable method of comparing seismic loading at different sites.

The information from this source should be the only information used as the input for selecting the seismic load factor. Even if other, possibly more precise, information is available, only this USGS source should be used. This is to ensure that dams will be ranked on a common basis.

Worksheet E - Seismic Response Factor for Embankment Dams

This Worksheet provides a simplified method to rank an embankment dam's failure potential under earthquake loading. The method is based on the premise that liquefaction of the foundation or embankment from earthquake loading creates situations that are much more serious to a dam's integrity than situations where no liquefaction takes place.

The first question asked is whether a liquefaction analysis has been conducted. In other words, have Standard or Becker Penetration Tests, or shear wave velocity data been collected; have the foundation and embankment been characterized in terms of representative residual shear strength and material continuity upstream to downstream and parallel to the dam axis; have seismic hazard curves been generated; and has a Seed simplified or some other liquefaction analysis been conducted? If all this has been done, there should be much more confidence in a conclusion that there is or is not liquefiable material present. In some instances there will be liquefiable materials present, but not in enough lateral extent to be able to cause a flow slide. In other instances a modification for a seismic dam safety deficiency has already been constructed which may not have adequately addressed the problems. The intent of this first question is that since an analysis has been done, there should be sufficient information available to make a judgement as to whether the dam is likely to sustain significant damage or immediate failure due to earthquake loading.

If there has been no liquefaction analysis done, the placement history of the dam and the dam's foundation give some indication regarding their liquefaction potential. Foundation or embankment materials that typically can be liquefiable include alluvium, lacustrian deposits, and sometimes loess. In general, any materials suspected to have been loosely deposited cannot be ruled out as non-liquefiable. Foundations consisting of bedrock, entire cross sections composed of materials with high clay content, or well compacted embankment materials can be ruled non-liquefiable. The potentially liquefiable foundation materials must also be expected to have continuity far enough under the embankment slopes and parallel to the dam axis to cause a flow slide.

If liquefaction, is known to exist (analysis done) or is suspected (analysis not done), will both the foundation and the embankment liquefy? Many more incidents of significant damage or near-failures have taken place where a poorly-compacted embankment (alone or in conjunction with a bad foundation) has been involved than when a well-compacted dam exists on a loose foundation.

If there is liquefaction, then how much freeboard is usually available? Vertical crest displacements of as little as 25% and as much as 50% of the embankment height have taken place when earthquakes have caused extensive liquefaction at dam sites. Use the normal water surface from design information unless there is an operation restriction on the reservoir, or unless there are many years of operational history where some lower reservoir can reasonably be expected. Note that height of dam is taken as streambed to dam crest.

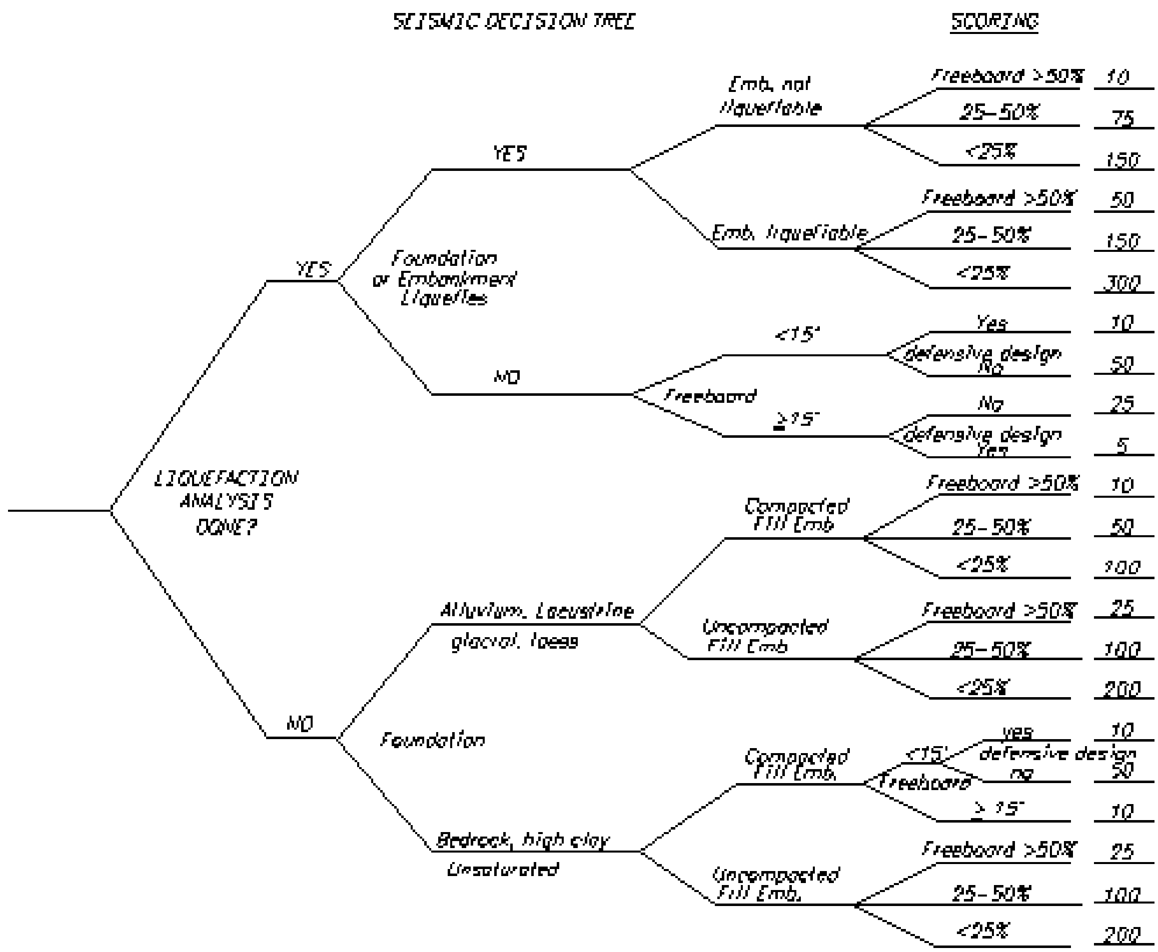
Special note for embankment dams with parapet walls:

> **Don’t** use parapet walls for calculation of dam height for embankment dams for the seismic worksheet E (even a good parapet wall is not likely to be of much use after the dam has settled following the earthquake).

If liquefaction does not take place, is the freeboard less than 15 feet? Typically, the crest of an embankment dam does not crack deeper than this. Water above the bottom of cracks might lead to failure, but there would be a much greater chance for successful intervention than if a flow slide causes the embankment to be overtopped. Dams designed with crack-stopping filters have a better chance to survive leakage than do embankments with no defensive designs. If the freeboard is greater than 15 feet, there may still be poor design features that could cause concern. Such instances might include dams where the impermeable barrier is very thin and is not protected by filters on its downstream side.

The above discussion is represented in the following logic diagram:

The following decision tree is represented by the scoring of this worksheet.



Worksheet F - Seismic Response Factor for Concrete Dams

Worksheet F of the Dam Safety Risk-Based Profile System is used in an manner very similar to that of Worksheet B (Static Loads for Concrete Dams) and provides a simple way of summarizing the performance of concrete dams when subjected to seismic loading conditions. After obtaining the score for the magnitude of the earthquake loads (as described in Worksheet D), the score for the ability of the concrete dam and foundation to resist these loads is obtained in this Worksheet. The three main categories for determining this performance include: Foundation/Geology, Dam Design, and Existing Condition of Concrete Dam. A maximum of 300 points are allocated among these categories. The items listed in each category are reviewed, checked if present at the dam being evaluated, and points are assigned and summed to determine the total Seismic Response Factor for the dam.

The main concerns with the seismic performance of concrete dams reflected in this Worksheet include:

- Potential foundation failure due to adverse orientations of jointing, faulting, or bedding planes. Any potential foundation failure modes for static loads will likely be more of a concern when seismic ground motions are also applied.

- The results of structural analyses performed for the dam for seismic loads and the absence of certain design features that are now considered necessary for the safe performance of concrete dams.

- The poor condition of the existing dam such as unbonded lift lines, excessive seepage, non-functioning drainage systems, or cracked or spalled concrete. These conditions alone may not necessarily point to a dam safety deficiency, but they may be indicators that performance of the dam is deteriorating or less than desirable during seismic shaking.

<u>Worksheet G - Operations, Maintenance, and Safety</u>

Worksheet G is used to identify and score issues that may not be dam safety deficiencies, but can present significant risk to the safe operation of the dam or to people working at the dam, visiting the dam, or living downstream of the dam. Several of these items often present the highest likelihood of loss of life at a dam. The remaining items are indicative of the attention paid to the Operations and Maintenance program at the dam.

One hundred points are assigned to this category. The items listed in this category are reviewed, checked if present at the dam being evaluated, and points are assigned and summed to determine the total Operations, Maintenance, and Safety Failure Index for the dam. The first five items could directly lead to loss of life or greatly increase the likelihood of failure or the uncontrolled release of the reservoir and are therefore given higher values. The last four items are less serious, but could develop into dam safety problems if ignored.

The main concerns reflected in this Worksheet include:

- Comparison of the capacity of one spillway or outlet gate to the safe downstream channel capacity. When the discharge from one gate can exceed the downstream channel capacity, the risk to downstream populations from a mechanical failure becomes much greater.

- The performance, maintenance, and operation of mechanical systems, primarily spillway and outlet gates. The satisfactory performance of spillway and outlet works gates in all situations and weather conditions is essential to the safe and reliable operation of the dam in making normal releases, passing flood inflows, and evacuating the reservoir in an emergency.

Note that when checking the box for backup power available to sites which use power to operate gate or valves, provisions for simple <u>manual</u> operation of the gates is not an 'adequate' source of power. However, if it is <u>documented in the SOP</u> that a backup source of power is a portable generator that is brought to the site in the event of an emergency then this would be considered an adequate source.

- Operations at the dam that are not in compliance with the Standing Operating Procedures. At some facilities, operation of the dam is made to fit a local concern or is operated to save time and money for the local operating entity. These deviations from the SOP can often lead to dam safety deficiencies and increase the risk to the downstream population.

- The existence of unsafe conditions for either the operations staff or the visiting public.

<u>Worksheet H - Loss of Life Factor</u>

A dam with a large human population living, working, or spending recreational time in an area inundated by a dam-break flood represents higher risk than a dam with little or no population downstream. Thus this RBPS produces an estimate of life loss rather than simply using a Population at Risk (PAR) value. The process used to estimate life loss conceptually follows the methods developed by Wayne Graham in "A Procedure for Estimating Loss of Life Caused by Dam Failure", DSO-99-06, September, 1999 with allowances made for this level of study. This worksheet estimates life loss by developing a weighting factor from this procedure.

If a previous risk analysis or hazard study has produced a life loss estimate, the PAR information can be useful in filling out this worksheet, but the actual life loss estimate should not be used. At some time in the future, if all dams in the inventory have a life loss estimate associated with them, this worksheet may be modified to work directly with that estimate. For now, in order to achieve a consistent ranking product, the life loss weighting factor developed in this worksheet should be used.

The weighting factor developed here is used as a multiplier to the previously calculated failure index. The weighting factor has a numerical value that depends on the number of people potentially exposed to dambreak flooding adjusted for warning time and flood severity effects. .

The potential for life loss primarily depends on the number of people exposed to serious flooding (the Population at Risk or PAR). The proportion of the PAR that could end up as fatalities then depends on the amount and quality of advance warning in relation to the flood wave travel time, the ability to evacuate, and the intensity of the flooding. Therefore, the weighting factor starts with the PAR, and then is adjusted depending on factors that influence the warning time or the flood intensity.

The procedure for estimating the loss of life weighting factor is summarized in the following steps:Step 1) Determine Population at Risk – Obtain available inundation maps and population information for the dambreak flood areas downstream from the dam.

There are many reasons why people are in an area that could be inundated by a dam break flood. They may live, work, or go to school in the area, they may spend the day fishing or spend several days at a campsite. They may be driving on roads or walking on scenic trails. They may be confined in places such as hospitals or prisons. Rapid economic development in some localities might cause a future PAR to be much greater than the present PAR. Census data from an almanac or from the Internet can be used to estimate PAR in towns. USGS maps can be used to determine the fraction of a town's area that might be inundated, or to count isolated houses. Field trips or telephone interviews might help determine the transient usage. As warning time and evacuation potential increase with distance from the dam, the PAR estimate's accuracy is more important in the first reaches below the dam where warning and evacuation would usually be minimal.

Population for any city in the United States may be obtained by linking to the following internet site: www.census.gov. A reminder that these are 1990 populations. You might want to increase these values for those towns where population has increased substantially in the last decade (increases in the 10% to 20% range are typical for explosive growth areas). Also remember that the population reported is for the whole town. What is really needed, however, is just the population inundated by the flood (definition of PAR). Therefore it is common practice to estimate the percentage of the town that is inundated (just a rough eyeball estimate) and use this percentage to multiply by the total population to get PAR. If you know for sure that much of the population is in the inundated area then you can also take this into account. Afterwards you need to follow the considerations given on the help button on worksheet H of the RBPS for the fast, deep flow considerations. All your decisions should get documented on the comment button of the RBPS as usual.

Step 2) Subdivide river reaches downstream from the dam. – Criteria for subdivision include significant changes in the valley width or in population density. Significant changes in valley width would entail a transition from a canyon situation to a flatland situation. A valley width change from 300 yards to a mile (considered at a height about 20 feet above the stream elevation) is significant, whereas a change from 1 mile to 3 miles is not. Significant population density changes might be from sparsely populated to medium-density, to densely populated as judgement dictates.

If no significant changes are apparent, use 4 sub-divisions: 0 to 5 miles, 5 to 10 miles, 10 to 15 miles, and greater than 15 miles. The population below 15 miles will not contribute much to potential life loss, however, it will be considered for the socio-economic rating.

A minimum of four subdivisions is recommended. There is no maximum number, though additional potential for life loss drops off significantly beyond approximately 15 miles, or about an hour and a half's travel time, from the point where unusual flooding is first detected. Effort to achieve accuracy in PAR estimates should decrease with distance downstream from the dam.

Should there be towns or cities in the area of concern, each population concentration should constitute a subdivision. For instance, if towns are located 3 miles and 8 miles downstream, and the valley width does not change significantly, use 7 subdivisions: 0 to 3 miles, 3 miles, 3 to 8 miles, 8 miles, 8 to 13 miles, 13 to 15 miles, and greater than 15 miles. Do not consider reaches much greater than about 5 miles in length within the first 15 miles.

Assign a single distance to each reach. If population is uniformly distributed between 0 to 5 miles, use 2.5 miles. If more people live toward the far end of the reach, assign 3.5 or 4 miles to the reach.

Consider situations where it is certain that the first detection of dam-break flows would not occur until the flood wave arrives some distance downstream from the dam. There might be some justification to do this for certain types of failure modes. These situations would be strong exceptions, only assigned to extremely remote dams. For these cases, consider beginning the 15-mile reach at the location of the first likely detection. Do not do this if the dam breach time is considered instantaneous (more on this below).

For hydrologic failure modes, huge spillway and outlet works releases would typically be inundating large areas below the dam just prior to a dambreak. The dambreak flood would then inundate an additional area. The PAR exposed to the additional dambreak flooding should be counted, and not the PAR exposed to extreme spillway and outlet releases just prior to the dambreak.

Step 3) Consider the time it would take for the dam to breach. – In other words, how long would it take before life-threatening flooding would be released by a potential dam failure? Should the dam take some time to fail, the PAR may be exposed to flooding that gradually becomes deeper and faster, improving their chance for escape to higher ground. The nature of the failure mode, the construction materials, and the dam design all play a part in the speed of breach formation.

First consideration should be given to the question: is it at all possible that the dam will be gone in an instant? This type of dam failure has rarely occurred in the past, but the flooding released from such failures is exceedingly devastating. Concrete dams such as St. Francis Dam and Malpasset Dam failed instantly. The only type of embankment dam that has failed instantly is a mine tailings dam. Liquefaction during an earthquake could cause a flow slide that would allow instantaneous overtopping, but it may be that the initial release over the failed section is no where near the flow quantity needed to wash away buildings. The initial release in this case may not even exceed safe channel capacity. Only if the majority of the embankment itself is considered liquefiable, should one consider the embankment capable of failing instantaneously. However, the RBPS will only assign a 'flood severity' rating equivalent to the 'moderate' category of DSO-99-06 for all embankment dams. The 'high' category is reserved exclusively for concrete dams.

If the dam cannot fail instantly, then what factors influence the speed of breach development?

a) Dam size - the time to remove a volume of material is directly proportional to the amount of material removed. Consider how much material has to be removed before life-threatening flooding results.

b) Erodability – silty-sand, low-plasticity, or low-density cores or dispersive clays erode easily while dense, plastic clay cores do not erode easily

c) Failure mode - A severe earthquake may cause instantaneous overtopping. It may severely crack the crest area, weakening the dam's resistance to erosion. Certain internal erosion failures may take hours or days to develop. Hydrologic loading could overtop the dam slightly for a short time, or it could overtop the dam by many feet and for many hours or days.

d) Dam design – rockfill shells may be capable of surviving many times the flow that would begin failing an earthfill shell. A very thin core may resist erosion for a long time, but then breach suddenly when undermined.

e) Reservoir storage – very small reservoirs may empty before a breach can develop fully.

The choices for breach development speed are instantaneous, fast, moderate, or slow. Breach development times assigned by this ranking system to fast, moderate, and slow are: 15 minutes, 45 minutes, and 90 minutes. Many dams have taken more than 90 minutes to fail, but in the present calculation, 90 minutes will achieve the intended purpose of placing all PARs into the "adequate" warning time category (more on this below).

Step 4) Consider the nature of the peak flow at the PAR's location. - For each PAR, estimate the percentage of the total population that is likely to be exposed to deep and fast flow (flow capable of severely damaging or destroying houses) when the dam break flood is at its peak flow. PARs located in areas where deep and fast water will flow are more likely to die than those located where floodwater would run shallow and slow (flow that still has some potential to kill, but does only moderate or no structural damage to houses). This percentage is difficult to estimate since there is usually not a lot of essential information available. However, one can usually get a general sense by considering the valley width, the ground slope perpendicular to the river, and the height above the river where the populations are located. Also, rivers usually have floodplain terraces that show up on the topographic maps. Those terraces closest to the river are most likely to be exposed to the deep and fast flows. Use 50 percent if there is there is a perception that neither type of flow is more likely than the other.

Step 5) This step is internal to the program. - Wayne Graham's procedure (DSO-99-06 referenced above) includes warning time categories (none, some, and adequate) and a determination of how an evacuation message might be perceived by the PAR. The amount of advance warning depends on the flood wave travel time with respect to the PAR's location downstream from the dam. Those close to the dam will have a smaller time margin. Historical events have shown that in most dam break cases, almost all fatalities occur within 90 minutes of flood wave travel time (or approximately 15 miles downstream from the dam). Beyond that, warning tends to be very effective. The program calculates a warning time based on the PAR's distance from the point of earliest dam failure detection and the time it takes for the dam breach to form.

The type of failure mode can influence warning time. Extreme flood events in very large drainage basins take significant time to develop, during which heightened awareness and monitoring usually take place. Overtopping situations will normally have several hours or even days of advance warning under these conditions. In small basins, the floods develop much quicker, so life threatening events would have less advance warning. Internal erosion failures would, under most conditions, give many hours of advance warning if an effective monitoring system exists at the dam. Earthquake failure modes are expected to give the least amount of warning, unless the downstream public is aware that the dam that threatens them has a potential to fail under earthquake loading and are prepared to evacuate without notification (the earthquake itself would then be the notification).

The types of evacuation message have the categories "vague" and "precise" in Graham's method. Trying to predict how an evacuation message might get communicated was thought to be beyond the experience of most people filling out this data base. A simplification has been made that assumes if an emergency action plan exists for the dam, there is a good chance that the authorities will be able to understand what needs to be done, and will effectively communicate the directions to the PAR. If, in spite of the fact that an EAP exists for the dam, the user thinks the warning effectiveness will be problematic, they should check "EAP – No" in the appropriate box and explain why in the commentary.

The equation used to determine warning time category is:

$$\frac{\text{Dist. D/S} - \text{Dist. D/S of First Notice}}{\text{10 miles per hour flood travel speed}} + \text{Breach Development Speed} - \text{Failure Mode Factor}$$

where the Breach Development Speed is .25 hour, .75 hour or 1.5 hours depending on the user's choice of fast, moderate or slow. The Failure Mode Factor is .375 (between 15 minutes in the day and 30 minutes at night) for Internal erosion or Seismic failure modes, and .125 (between 0 minutes in the day and 15 minutes at night) for Hydrologic failure modes. If this equation results in .25 hour or less, the warning time category is "none". Between .25 hour and 1 hour, the category is "some". Greater than 1.5 hours is "adequate".

The following logic tree can be used to help in understanding the computation of the life loss: